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DESIGN AND CONSTRUCTION OF A 4 KW, 500 MHZ SOLID STATE RF AMPLIFIER AT IRANIAN LIGHT SOURCE FACILITY (ILSF)

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Abstract

Solid state RF power amplifiers have been considered as an attractive candidate for providing the high power RF power required in increasing number of accelerator applications in recent years. Due to the advantages of these amplifiers and based on the successful experience done in other light sources; ILSF RF group has started R&D in design and fabrication of solid state amplifiers. Two modules based on two different LDMOS transistors have been developed successfully at 500MHz. The measured characteristics are presented and compared in this paper. Combining of 8 such modules is under test to achieve 4kW output power as the first stage of the conceptually designed combining network. This paper outlines the design concept of the different parts of the amplifiers and presents the experimental results obtained so far.

INTRODUCTION

The Iranian Light Source Facility (ILSF) RF system was conceptually designed in accordance with the requirements for ILSF 3GeV storage ring with 400mA beam current at 500 MHz RF frequency. Based on the successful experience carried out in SOLEIL and afterward in many other light sources (such as LNLS, SLS, ESRF) and also existence of local expertise in Iran, solid state amplifiers have been chosen as RF power sources to bring their advantages; modularity, easy maintenance and graceful degradation to ILSF storage ring and booster RF systems [1]. The development of the solid state amplifiers at ILSF initiated with the design and fabrication of two amplifier modules based on BLF578 and MRFE6VP1K25HR6 transistors. Their test results are presented and compared in the next section of this paper. Combining of 8 modules is under test to achieve 4kW output power as the first stage of the 200kW conceptually designed combining network [2]. The design of its components and the experimental results obtained so far will be also included in this paper.

AMPLIFIER MODULES

In order to achieve the required output power with acceptable efficiency to drive the cavities, the modules should be designed in such a way to deliver their maximum power with optimized efficiency. Since two types of RF transistor, BLF578 and MRFE6VP61K25H, are released at high power with almost the same characteristics at 500MHz [3,4], both of them have been chosen for evaluation of their performance.

The first module (Module1), which is designed based on BLF578 transistor, is mounted on a copper plate and finally placed on an aluminum cooling bar, as shown in Fig.1. Whilst the second module (Module2) with MRFE6VP61K25H transistor, is mounted on a copper plate that is cooled directly, Fig. 2.

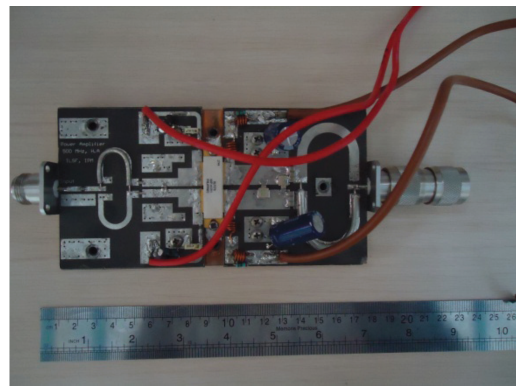

Figure 1: ILSF RF Module1 (based on BLF578).

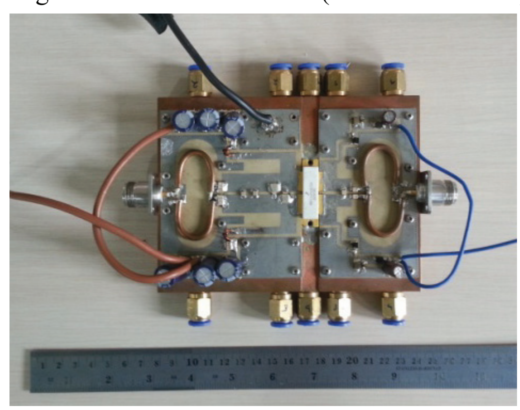

Figure 2: ILSF RF Module2 (based on MRFE6VP61K25H).

Both ILSF developed modules have been tested at SESAME, with the purpose of making a comparison between RF solid state amplifier modules made at ILSF and those made by Soleil for SESAME. Their measurement results are described in Table 1. A glance at this information reveals that P_{1dB} and efficiency of Module 1 are much better than those related to Module2. Thus, further modifications have been recently made on Module1 in order to improve its efficiency while the optimizations on Module2 is still in progress to improve its overall performance. The accurate measurements have been done on Module1 and Module2 (as it is) at ILSF to extract their performance characteristics more precisely. So, the clamp current meter, that may suffer from the radiated power, was replaced with a shunt precise resistor and also a DCCT to read the current more accurately. Moreover, the overall insertion loss was measured by vector network analyzer. The measurement results (see

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Fig. 3 – 4) show that the efficiency and gain of Module1 went up to 67% and 17.7dB, respectively (at P_{1db}=690W), which is a great improvement comparing to the previous test results. As can be seen also in Fig. 3, the output power of Module1 increases linearly when the input power climbed up. In contrast, the output power linearity of Module2 is not satisfactory.

Weighing up the pros and cons of both modules encouraged us to use Module1 as a constructive module for 4KW amplifier although, further modification on Module2 is still in progress.

Table 1: ILSF Modules Test Results

Characteristics	Module2*	Module1*	Module1**
$P_{out,1dB}$(W)	660	690	690
Gain at 1dB compression point (dB)	19.7	16.9	17.7
Efficiency (%)	53.7	56	67

* Results of the mutual test performed with SESAME staff at SESAME , Oct. 2013.
** Last results achieved at ILSF after modification, 2014.

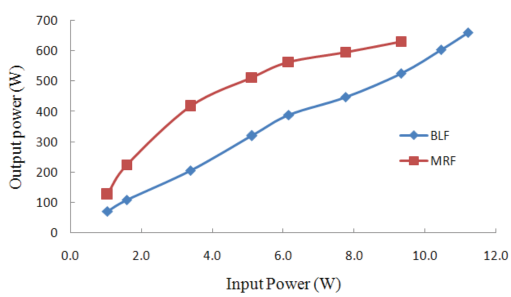

Figure 3: P_{out} versus P_{in}.

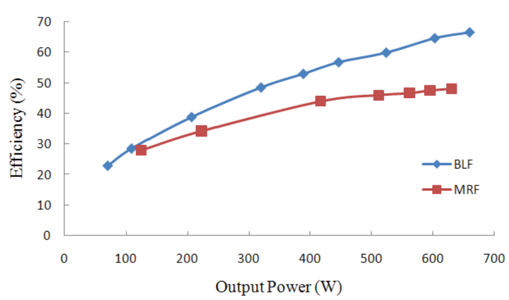

Figure 4: Efficiency versus P_{out} .

4KW AMPLIFIER

Based on the conceptually designed combining network for delivering required power to the cavity, output power of eight modules should be combined in order to achieve 4KW power at the first stage. As mentioned before, Module1 has been chosen for designing 4KW amplifier due to its better performance characteristics. Furthermore, this amplifier includes 1:8 power divider, 8:1 coaxial power combiner, power supply and controller units and also a new designed heat sink that are demonstrated in Fig. 5. Here, some of these components are described briefly.

Power Supply and Controller

This unit provides smooth drain DC voltage to each module. Using Multiphase Synchronous Buck Converter (MSBC) technology enables this unit to work properly with the efficiency of better than 90%. The output voltage, current, transistor temperature and RF signal can be monitored and the required protections can be applied by this unit. Serial bus (RS485) is assumed for its communication. A high power AC(3 phase) to DC (60V) convertor feed in eight such power supply units which are mounted on the module heat sinks. These units are under fabrication in ILSF power supply group and will be installed in the final structure soon.

Coaxial Power Combiner

Power combiners are major parts of solid-state power amplifiers. The combiner may be binary in form, using two-to-one junctions in cascade or may use non-binary structure that combine the input power at one step. This type of combiners has arbitrary number of inputs (3, 5, 8 and etc.). The radial coaxial power combiner, by nature of its geometry (second type), tends to minimize loss. So we use this type of power combiner to gather the output power of modules at 4KW amplifying step. This type of power combiner is used without any isolation resistor, so each module must be protected with an isolator to decrease the interaction between adjacent modules. A circulator has been used in each module for this purpose.

The coaxial combiner is designed based on the procedure mentioned in [5,6] and is simulated by HFSS, as well. It is consisting of 8 N-type circumferential ports (as input ports) and an EIA-1 5/8” output port. The scattering parameters of the structure (Fig. 6) are measured at low power regime by using four port vector network analyzer. As shown in Fig. 7, there is a good agreement between simulation and measurement results. Its main characteristics are listed in Table 2.

Power Divider

A 1:8 Microstrip power divider is also designed and fabricated at ILSF. For compensating modules’ phase mismatch which might degrade the combining efficiency, phase shifters have been envisaged in the output paths of the divider. They can provide 10-20 degree phase shift to each module.

Measurement Results

The performance of the 4KW amplifier is evaluated at ILSF by using simple power supplies (with only a current limiter), since the final version is still under fabrication. Using these simple power supplies, the output power of 2.2kW has been achieved so far with the efficiency of about 50% that was predictable as the modules are working at lower power. The final test will be done soon with the final power supply units as further protections at higher power are unavoidable.

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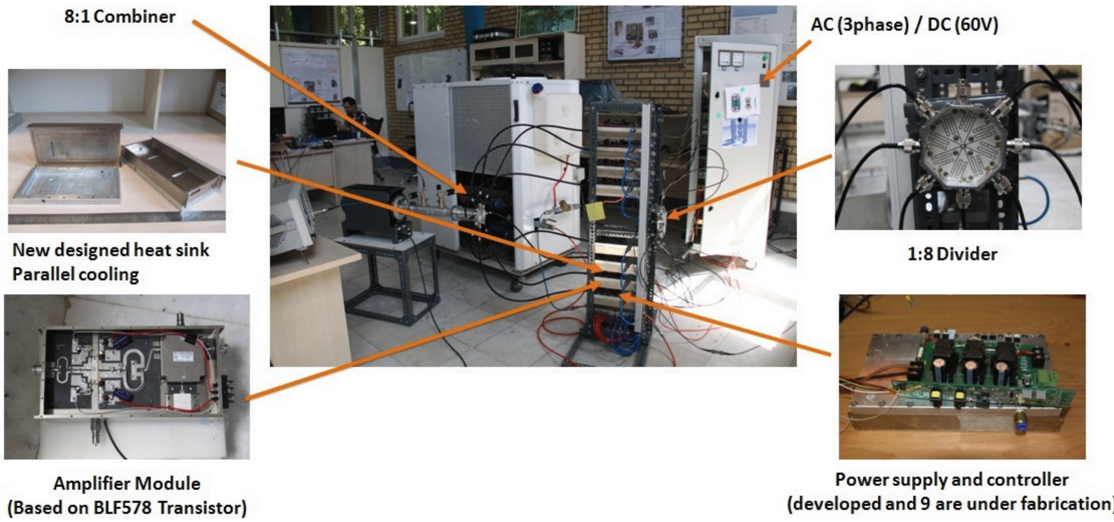

Figure 5: 4KW amplifier and its constructive components.

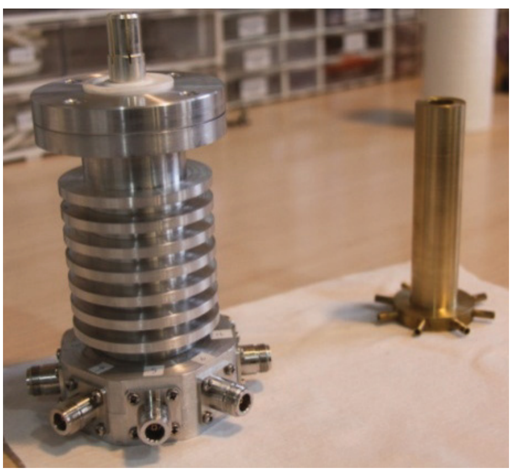

Figure 6: The radial coaxial combiner (4KW). Whole structure (left one) and inner conductor (left one).

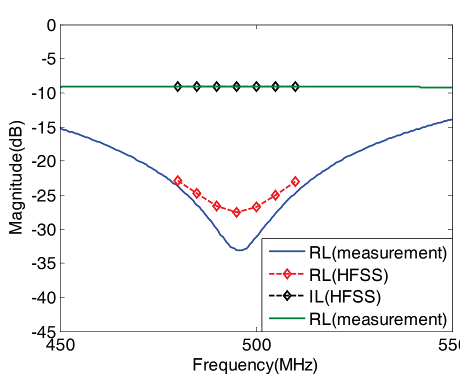

Figure 7: Return loss (RL) of common port and insertion loss (IL) between the common port and circumferential ports of combiner.

Table 2: Characteristics of Coaxial Combiner

Maximum insertion loss	0.1dB at 10% BW
Common port return loss	20dB
Minimum isolation	16dB
Phase imbalance	$< \pm 0.05$dB
Amplitude imbalance	$< \pm 1^{o}$

CONCLUSION

Two different amplifier modules have been developed and practically compared at ILSF as the main part of the RF solid state amplifier. Combining of 8 modules is under test to achieve 4kW output power as the first stage of the 200kW conceptually designed combining network. The design of the final amplifier including its combining network, structure, cooling and power supplies, will be reviewed, and finalized according to the test results of the 4kW amplifier.

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